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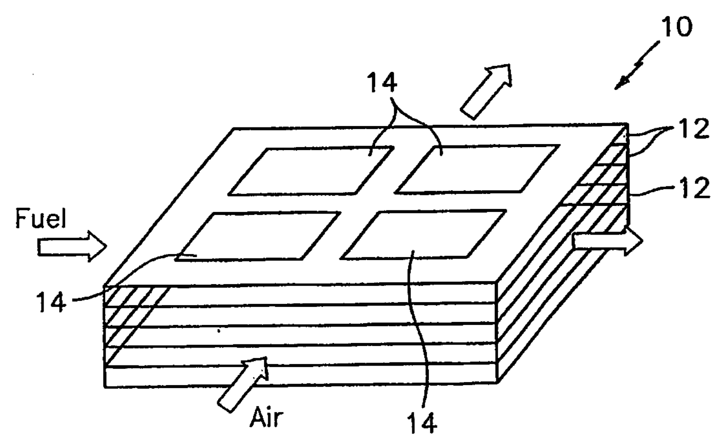
(54) Title: COMPLIANT STACK FOR A PLANAR SOLID OXIDE FUEL CELL



(57) **Abstract:** A fuel cell stack (10) formed of repeating cell units (12) is provided wherein each cell unit (12) includes a fuel cell having an anode side (20) and a cathode side; an anode side frame (18); a cathode side frame (28); a bipolar plate (24) having an anode side interconnect adjacent to the anode side frame (28) and a cathode side interconnect adjacent to a cathode side frame (28) of an adjacent cell unit; a cathode side seal (26) between the fuel cell and the cathode side frame; and an anode side seal (22) between the fuel cell and the anode side frame, wherein at least one of the anode side interconnect, cathode side interconnect, anode side seal (22) and cathode side seal (26) are compliant.

WO 2005/034277 A1

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COMPLIANT STACK FOR A PLANAR SOLID OXIDE FUEL CELL

Cross Reference to Provisional Application

[0001] This application claims the benefit of provisional application serial number 60/506,936, filed September 29, 2003.

Background of the Invention

[0002] The invention relates to planar solid oxide fuel cell stacks and, more particularly, to a planar-solid oxide fuel cell stack design which increases the footprint of the stack.

[0003] It is essential from a cost reduction standpoint to increase the footprint of the solid oxide fuel cell (SOFC) stack in the plane of the cell. One approach to achieve increased in-plane footprint is to manufacture and use SOFC cells that are bigger in length and/or width in the stack. Manufacturing ceramic SOFC cells of increased dimensions and maintaining them within acceptable tolerances is fundamentally difficult. At this time, several cell manufacturers produce 4″ x 4″ (10 cm x 10 cm) cells within acceptable dimensional tolerances. Cell manufacturers are presently attempting to produce 8″ x 8″ (20 cm x 20 cm) cells within acceptable tolerances. Acceptable tolerances are needed to prevent cell fracture during assembly and operation of the stack. Fundamentally, from a ceramics processing standpoint further increases in size are extremely difficult and probably not cost effective. In addition, the use of larger cells raises thermal management concerns during electrochemical operation since the temperature across the cell increases with increasing in-plane cell dimension. Prior art stack designs typically use bonded glass seals and/or non-

compliant interconnects and, therefore, are not easily amenable to in-plane foot print scale-up.

[0004] It is clear that the need exists for a fuel cell stack structure which reliably provides for in-plane foot print scale up, and it is the primary object of the present invention to provide such a structure.

[0005] Other objects and advantages of the invention will appear herein below.

Summary of the Invention

[0006] According to the invention, the foregoing objects and advantages have been readily attained.

[0007] According to the invention a fuel cell stack is provided which is formed of repeating cell units, wherein each cell unit comprises: a fuel cell having a trilayer structure of an anode electrode, an electrolyte, and a cathode electrode; an anode side frame; a cathode side frame; a bipolar plate having an anode side interconnect adjacent to the anode side frame and a cathode side interconnect adjacent to a cathode side frame of an adjacent cell unit; a cathode side seal between the fuel cell and the cathode side frame; and an anode side seal between the fuel cell and the anode side frame, wherein at least one of the anode side interconnect, anode side seal, cathode side interconnect, and cathode side seal are compliant, or pairs of anode side interconnect and anode side seal may be compliant and pairs of cathode side interconnect and cathode side seals may be compliant.

[0008] According to the present invention, the anode side frame has one or more openings into which are seated one or more fuel cells. Each of these openings includes a groove, or recessed landing, along the perimeter thereof. The anode side seal and fuel cell both seat in the recessed

land of the anode frame opening, and the anode electrode of the fuel cell faces the anode seal. The cathode side frame and cathode side seal include one or more openings, these openings being coincident with the openings in the anode side frame.

[0009] Use of compliant seals and interconnects allows for a floating fuel cell which is more likely to resist stresses even at large in-plane foot prints, and also allows for avoidance of cell fracture from excessive compressive loads on the cell as well.

Brief Description of the Drawings

[0010] A detailed description of preferred embodiments of the present invention follows, with reference to the attached drawings, wherein:

[0011] Figure 1 is a perspective view of a solid oxide fuel cell stack according to the invention;

[0012] Figure 2 is an exploded view of a cell stack assembly according to the invention; and

[0013] Figure 3 is an exploded view of an alternative embodiment of a cell stack assembly according to the invention.

Detailed Description

[0014] The invention relates to a fuel cell assembly and, more particularly, to a solid oxide fuel cell (SOFC) stack having improved compliant interconnects and/or seals.

[0015] While the 3D compliant stack (i.e., compliant in all three orthogonal axes) of the present invention can inherently tolerate larger cell dimensional variations and thereby allow the use of larger cells of lower dimensional quality than prior art systems, the 3D compliant stack also

enables in-plane foot print scale-up in ways not achieved before. The main reason for increased in-plane foot print scale-up capability is that the stack is 3D compliant through at least one of, and preferably all of, compliant interconnects, compliant seals and resulting floating cells. As a result, dimensional variations that exist from one cell to another can be tolerated, because the compliant design limits local bending stresses to avoid fracture of the brittle ceramic cell. Floating, as used herein, means mechanically decoupled so that forces are not transferred from one component to another. For example, floating may be achieved by permitting relative motion between portions of the structure.

[0016] In addition, the seals are floating and do not bond to the mating surfaces. As a result, thermal gradients in the cell as well as thermal stresses during transient conditions are accommodated by relative movement, or sliding, in the seal area.

[0017] Compliant structures are described in greater detail in commonly assigned U.S. Patent Application Serial Number 10/758,843, filed January 16, 2004, and incorporated herein by reference. Compliant seals are further described in commonly assigned U.S. Patent Application Serial Number 10/622,881, filed July 18, 2003, and incorporated herein by reference.

[0018] This invention provides a stack design having the ability for increased in-plane footprint and thereby enables cost effective scale-up of SOFC stacks. As an added benefit, the stack design permits cooling channels to be built integral to the assembly thereby minimizing thermal gradients across the cell and enhancing stack structural robustness and electrochemical stability.

[0019] A fuel cell stack may be formed of repeating cell units, wherein each cell unit comprises: a fuel cell having a trilayer structure of an anode electrode, an electrolyte, and a cathode electrode; an anode side frame; a cathode side frame; a bipolar plate having an anode side interconnect adjacent to the anode side frame and a cathode side interconnect adjacent to a cathode side frame of an adjacent cell unit; a cathode side seal between the fuel cell and the cathode side frame; and an anode side seal between the fuel cell and the anode side frame, wherein at least one of the anode side interconnect, anode side seal, cathode side interconnect, and cathode side seal are compliant, or pairs of anode side interconnect and anode side seal may be compliant and pairs of cathode side interconnect and cathode side seals may be compliant.

[0020] According to the present invention, the anode slide frame has one or more openings into which are seated one or more fuel cells. Each of these openings includes a groove, or recessed landing, along the perimeter thereof. The anode side seal and fuel cell seat in the recessed land of the anode frame opening, and the anode electrode of the fuel cell faces the anode seal. The cathode side frame and cathode side seal include one or more openings, these openings being coincident with the openings in the anode side frame.

[0021] Figure 1 shows a cross flow stack 10 consisting of several layers of repeating cell units 12. One plane of stack 10 is shown where four fuel cells 14 are arranged in a substantially square geometry. An anode side frame with four openings (similar to a window frame) supports the four cells at their perimeters. The anode side frame resembles a window frame, wherein each opening has a recessed land or

groove along its entire perimeter. The recessed land, which will be referred to as a groove, serves as the seat of one anode side seal, on top of which one fuel cell seats with the anode electrode facing the seal. In this arrangement, the fuel cell resembles a pane of a window.

[0022] Figure 2 is an expanded view of the repeating cell unit 12 of stack 10. Fuel cells 14 seat in a groove 16 in an anode frame 18 where the anode side 20 of cell 14 is sealed using a compliant seal 22. A 3D compliant bipolar plate 24, compliant cathode seal 26 and cathode frame 28 are assembled as shown in Figure 2. Since fuel cells 14_are inside groove 16 and sealed using two compliant seals 22, 26, the cells are not subjected to the clamping load normally exerted on the frame and as such the cells are referred to as floating cells. The heights of interconnects, seals, grooves and frame are formed, net-shape processed, or machined to accept a nominal thickness of the cell thickness. The floating cell and the 3D compliance of the seals and interconnects advantageously allows variations in cell thickness and cell curvature to be accommodated without cell damage or fracture.

[0023] In the stack assembly process, thin layers of contact or bonding material may be used between the anode electrode of fuel cell 14 and the anode side interconnect so as to improve electron transfer and minimize the interface ohmic resistance. Similarly, thin layers of contact or boding material may be used between the fuel call electrode and cathode side interconnect.

[0024] While Figure 2 shows bipolar plate 24, anode frame 18 and cathode frame 28 as separate parts, for the sake of clarity, these parts can advantageously be bonded together by one of several metal-joining processes well

known in the art to form a single part. If bipolar plate 24 and the anode and cathode frames are used as separate parts in assembling a stack, then a flat compliant seal similar to the cathode side seal shown in Figure 2 may be used between the pairs of anode frame-separator plate and cathode frame-separator plate.

[0025] The window-frame stack design shown in Figure 2 can be manifolded in a number of ways such as 1) external fuel and external air manifold, 2) internal fuel and external air manifold, 3) internal fuel and internal air, and other similar combinations. In the window-frame design the external surfaces of the stack are essentially made up of the shallow external planes of frames and separator plates, which are made of metallic materials. Dimensional control of metallic material parts is much better than ceramic materials and the window-frame stack design would make the application of external fuel and external air manifold possible and the external manifolds may be expected to lead to lower stack costs. Figure 2 shows slots 30 for gas stream flow across the cells and the stack assuming the stack is externally manifolded. These slots are preferably properly sized for flow control across a cell plane and between cell planes.

[0026] Figure 3 shows the use of channels 32 formed into the anode and cathode frames to bring in and take out cooling fluids. These cooling fluids may be air, fuel, water vapor, helium, liquid metals, or any other medium that accomplished the function of cooling the stack. In one example, endothermic processes such as fuel reforming may be done in these channels. These fluid channels may be used to integrate the stack with combined heat and power (CHP), numerous bottoming cycles or other thermal

management integration options. These channels can be manifolded using means commonly known to the industry. Those skilled in the art will realize numerous alternate ways to arrange the flow fields of the reactants as well as the cooling fluid. These commonly known alternate methods are within the scope of the invention.

[0027] The stack in-plane foot print and the fuel cells are illustrated in the figures and described in the example as of a substantially square, '2x2' array, geometry. It will be understood by those skilled in the art that the fuel cell arrangement in a window frame architecture can be a 'MxN' array, wherein 'M' fuel cells are disposed in one direction and 'N' fuel cells are disposed in a substantially orthogonal direction and all the space is filled.

[0028] In another embodiment, the stack may have an in-plane foot print geometry that is rectangular (as with a 4x2 cell arrangement). In another embodiment, the stack consists of rectangular cells arranged in an equal matrix (e.g. 4x4) or non-equal matrix (e.g. 4x2). In another embodiment, the stack may have a substantially circular or oval in-plane foot print and may use substantially circular or oval shaped cells. Although 4x4 and 4x2 matrices are used as examples, the in-plane foot print may be of any number of cells. Those skilled in the art will realize numerous alternate ways to arrange the cells and the in-plane footprint. These commonly known alternate methods are also covered by the invention.

[0029] The invention disclosed herein may serve to reduce stack cost, permit multiple cells to be assembled to increase stack in-plane foot print using a window frame type architecture, permit flow of cooling fluids to

mitigate thermal gradients and manage thermals across the in-plane footprint. The planar SOFC stack design disclosed in this invention enables the fabrication of larger name plate capacity stacks and leads to the assembly of large capacity integrated energy systems such as cooling heat and power (CHP) products for commercial buildings and SOFC gas turbine hybrid systems of high efficiency for distributed generation of electric power.

[0030] It is to be understood that the invention is not limited to the illustrations described and shown herein, which are deemed to be merely illustrative of the best modes of carrying out the invention, and which are susceptible of modification of form, size, arrangement of parts and details of operation. The invention rather is intended to encompass all such modifications that are within its spirit and scope as set forth in the appended claims.

WHAT IS CLAIMED IS:

1. A solid oxide fuel cell stack formed of repeating cell units, each cell unit comprising:

a solid oxide fuel cell having an anode side and a cathode side;

an anode side frame;

a cathode side frame;

a bipolar plate having an anode side interconnect adjacent to the anode side frame and a cathode side interconnect adjacent to a cathode side frame of an adjacent repeating cell unit;

a cathode side seal between the fuel cell and the cathode side frame; and

an anode side seal between the fuel cell and the anode side frame, wherein at least one of the anode side interconnect, cathode side interconnect, anode side seal and cathode side seal are compliant.

2. The solid oxide fuel cell stack of claim 1, wherein the anode side interconnect and the cathode side interconnect are compliant in three dimensions.

3. The solid oxide fuel cell stack of claim 1, wherein each of the anode side interconnect, cathode side interconnect, anode side seal and cathode side seal are compliant.

4. The solid oxide fuel cell stack of claim 1, wherein the anode side frame and the cathode side frame define openings within which fuel cells are held.

5. The solid oxide fuel cell stack of claim 4, wherein the openings have a size of at least about 4 inches by 4 inches.

6. The solid oxide fuel cell stack of claim 4, wherein the openings have a size of at least about 8 inches by 8 inches.

7. The solid oxide fuel cell stack of claim 1, wherein the anode side frame has a groove formed on an anode facing side, and wherein the anode side seal is a compliant seal positioned in the groove.

8. The solid oxide fuel cell stack of claim 1, wherein the cathode side seal comprises a substantially flat compliant member.

9. The solid oxide fuel cell stack of claim 8, wherein the anode side frame has a plurality of openings within which anode side seals and fuel cells are positioned, and wherein the cathode side frame and the cathode side seal include openings coinciding with the openings in the anode side frame.

10. The solid oxide fuel cell stack of claim 8, wherein the cathode side frame has a plurality of openings within which fuel cells are positioned, and wherein the anode side frame and anode side seal include openings coinciding with the opening in the cathode side frame.

11. The solid oxide fuel cell stack of claim 1, wherein the anode side frame and the cathode side frame further comprise slots for allowing flow of reactants to the fuel cell.

12. The solid oxide fuel cell stack of claim 11, wherein the anode side frame and the cathode side frame have openings within which fuel cell elements are positioned, and wherein the slots are positioned around the openings.

13. The solid oxide fuel cell stack of claim 1, further comprising cooling fluid channels in the anode side frame and the cathode side frame.

14. The solid oxide fuel cell stack of claim 13, wherein the fuel cell stack is adapted to carry out endothermic processes in the cooling fluid channels.

15. The solid oxide fuel cell stack of claim 1, wherein the cathode side seal includes a floating seal.

16. The solid oxide fuel cell stack of claim 1, wherein the anode side seal includes a floating seal.

17. A solid oxide fuel cell stack formed of repeating cell units, each cell unit comprising:

a solid oxide fuel cell having an anode side and a cathode side;

an anode side frame;

a cathode side frame;

a bipolar plate having an anode side interconnect adjacent to the anode side frame and a cathode side interconnect adjacent to a cathode side frame of an adjacent repeating cell unit;

a cathode side seal between the fuel cell and the cathode side frame; and

an anode side seal between the fuel cell and the anode side frame, wherein at least one pair of the anode side interconnect and anode side seal, and cathode side interconnect and cathode side seal are compliant.

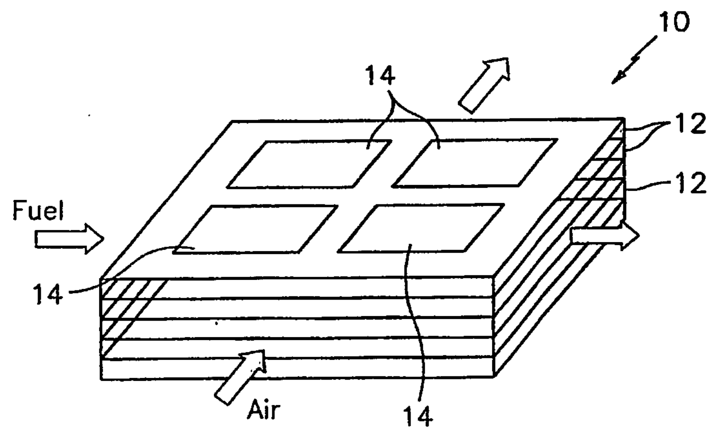

FIG. 1

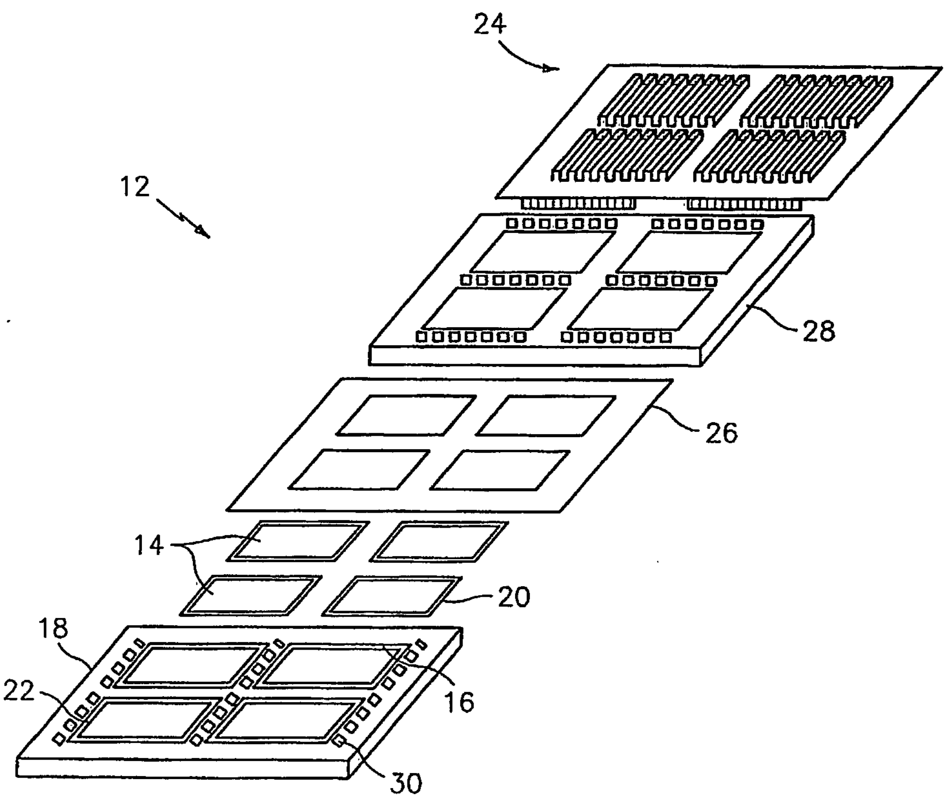

FIG. 2

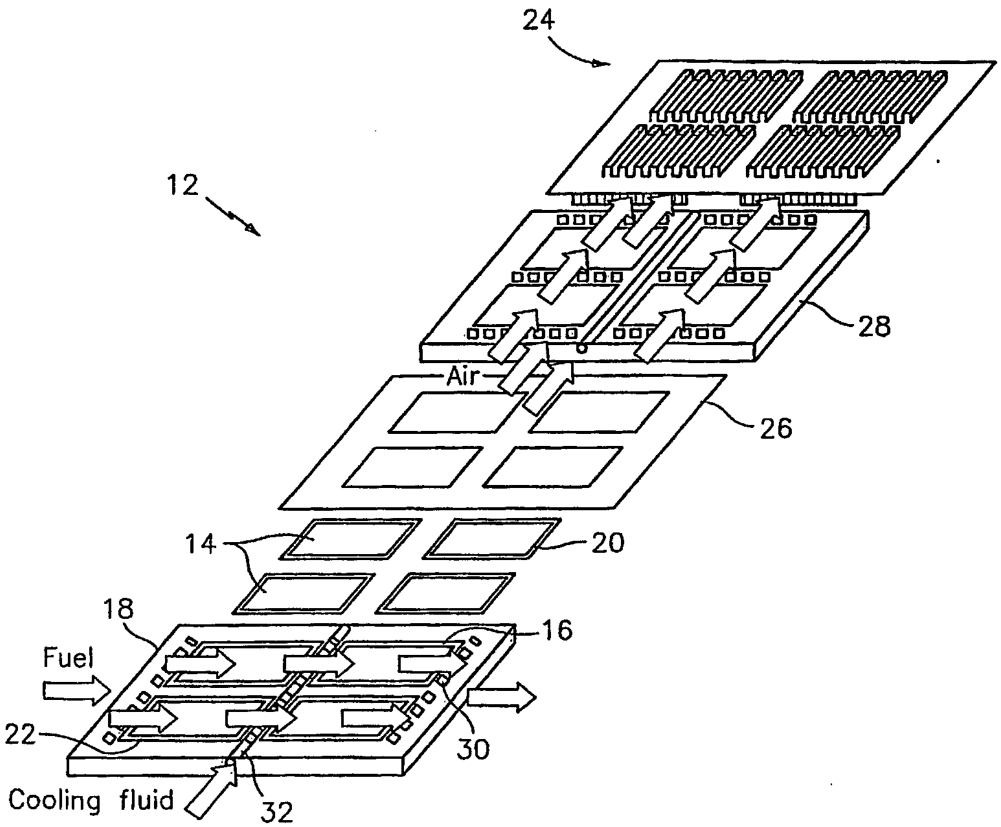

FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US04/32038

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) : H01M 008/12
US CL : 429/32, 33, 36
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 429/32, 33, 36

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Please See Continuation Sheet

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2003/0096147 A1 (BADDING ET AL.) 22 May 2003, see Ex 1, Figs. 2-4, 8, 9, paras. 0018, 0044, 0055-0057, 009-0101.	1-8, 11-13, 17
A	US 5,312,700 A (ISHIDA) 17 May 1994	1-17
A, P	US 2003/0235746 A1 (HALTINER, JR. ET AL.) 25 December 2003	1-17

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

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Continuation of B. FIELDS SEARCHED Item 3:
EAST
search terms: solid oxide fuel cell, anode frame, cathode frame, bipolar, interconnect